

## TOWARD DETECTING CALIFORNIA SHRUBLAND CANOPY CHEMISTRY WITH AIS DATA

CURTIS V. PRICE, TGS Technology, Inc., NASA Ames Research Center, M.S. 242-4, Moffett Field, CA 94035, USA; WALTER E. WESTMAN, NASA Ames Research Center, M.S. 242-4, Moffett Field, CA 94035, USA.

## ABSTRACT

AIS II data of coastal sage scrub vegetation from the Santa Monica Mountains were examined for fine spectral features that might be used to predict concentrations of certain canopy chemical constituents. A Fourier notch filter was applied to the AIS data and the TREE and ROCK mode spectra were ratioed to a flat field. Portions of the resulting spectra resemble spectra for plant cellulose and starch in that both show reduced reflectance at 2100 and 2270 nm. The latter are regions of absorption of energy by organic bonds found in starch and cellulose. Whether the relationship is sufficient to predict the concentration of these chemicals from AIS spectra will require testing of the predictive ability of these wavebands with large field sample sizes.

## INTRODUCTION

Strong interest exists in determining the concentration of leaf chemical compounds in canopies using fine spectral features of Airborne Imaging Spectrometer (AIS) data (Spanner et al. 1985; Spanner & Peterson 1986; Swanberg & Peterson 1987; Wessman et al. 1987; cf. Westman & Price 1987). Our interest in this application of AIS is spurred by the observation that particular air pollutants can induce distinct chemical changes in leaves of some species, both in fumigation studies, and apparently along field gradients in these pollutants (Westman 1987). The ability to identify such chemical changes remotely might thus permit both the identification of air pollutants as stressors, and the separation of influence of different pollutants in a multipollutant atmosphere on the species of interest. The physical basis for the postulated relationship between leaf chemistry and reflectance lies in the narrow absorption features, induced by vibrational stretching frequencies of organic bonds, that are embedded in the reflectance spectrum.

We present progress in analyzing AIS data of the Santa Monica Mountains of Los Angeles, California. This coastal range experiences inputs of pollutants from urban sources, particularly at the eastern end. In combination with daytime offshore winds, these conditions create a predominant diurnal west-east gradient of decreasing pollutant exposure, particularly in photochemical oxidants (Westman 1987). Our study objectives include the derivation of spectral reflectance curves in the 800-2400 nm range from selected sites of coastal sage shrubland arrayed along the pollution gradient for comparison with canopy chemical data obtained from field sampling.

## THE STUDY AREA AND POLLUTANT EFFECTS

Coastal sage scrub is a drought-deciduous, seasonally leaf-dimorphic shrubland type that occupies approximately 25% of the Santa Monica Mountains area, mostly at lower elevations in the western portion of the range. The location of the vegetation type in the Santa Monica Mountains has been mapped using Thematic Mapper Simulator data by Price and Westman (1987). The vegetation includes occasional individuals of evergreen habit, such as the laurel sumac, Rhus laurina. The latter often occurs as large clumps of 5-8 m diameter within the shrubland.

Ten species of coastal sage scrub were exposed for ten weeks to three levels each of ozone (0.1, 0.2, 0.4 ppm) and sulfur dioxide (0.05, 0.2, 0.5 ppm) alone and in combinations, and a filtered-air control, in fumigation chambers at the Statewide Air Pollution Research Center at the University of California, Riverside (Westman et al. 1985). The leaves remaining attached to the fumigated plants (5 plants in each of two replicates per treatment) were analyzed for plant pigments (chlorophylls a,b; total carotenoids), structural components (cellulose, fiber, lignin) and elemental content in five of the species (Artemisia californica, Rhus laurina, Eriogonum cinereum, Salvia mellifera, Encelia californica). Ozone treatment caused significant increases in leaf nitrogen, potassium and lead, and weaker trends toward increase in structural components and chlorophyll. Sulfur dioxide treatment induced significant rises in total sulfur. Combinations of the two pollutants caused a rise in sulfur and decline in carotenoids (Westman 1987). In the field, these sample species showed chemical changes from west to east that would be expected from the known rise in ozone levels toward the east: a rise in nitrogen and chlorophyll, and to a lesser extent in structural compounds (Westman 1987). These chemical changes may arise from accelerated leaf drop, and the consequent enrichment of the canopy in young, though stunted, leaves (Westman 1987). This and other hypotheses are currently being tested with additional field data.

## METHODS

AIS-2 data were collected over 15 study sites in the Santa Monica Mountains on September 15, 1986 by the NASA Ames C-130 aircraft. TREE (800-2100 nm) and ROCK (1100-2400 nm) mode data were obtained for all sites.

The raw imagery contained intermittent striping, dropped lines, noisy data lines, and blank image columns. Gain differences between image columns occurred due to varying responses between detectors. Periodic gain changes also occurred within an image column due to changes in detector response over time. These effects were expressed as vertical and horizontal striping in the imagery, respectively. Loss of certain lines on some flightlines occurred during the process of decommutating the high-density tape to computer-compatible tape. Several image columns (column numbers 1164,1985,1986) were zero for all pixels in the flight lines. Also the first column in each band contained noise.

Striping in the imagery was eliminated by replacing noisy image lines that occurred intermittently in Bands 1-32 with an average of

neighboring lines, and then applying a Fourier notch filter to the imagery as described by Hlavka (1986). This method for destriping the data is superior to a column by column flat-field division in that horizontal striping is removed and the original intensity (DN) values are preserved.

A section of freeway (Interstate 5) near Griffith Park, at the eastern end of the Santa Monica Mountains, was used to obtain flat field spectra in TREE and ROCK mode. The spectra represent an average of three rows for all 64 columns of pixels. Wavelength calibration was performed using supplied values (Jet Propulsion Laboratory 1986) for all 128 bands in ROCK mode, and for bands 65-128 in TREE mode. Bands 1-64 of TREE mode were calibrated using the 935 nm atmospheric absorption band (Chahine 1983).

AIS data were collected over areas of Rhus laurina of different densities in the La Jolla Canyon region of the western Santa Monica Mountains. Two weeks later, field measurements were taken of Rhus laurina shrubs using the Barringer REFSPEC IIA, an integrating sphere ratioing spectroradiometer. The instrument was suspended 0.5 m above the canopy so that the measured target contained several leaves in the uppermost layer of canopy. The latter data were ratioed to reflectance from a barium sulfate plate observed under the same conditions.

To compare AIS spectra of vegetation to plant chemical constituents, we digitized spectral reflectance curves for starch (from corn), liquid water (the difference between water-soaked filter paper and dry filter paper; in Hruschka and Norris 1982), and cellulose (in Norris and Barnes 1976). We converted data from log (1/R) to R, where R is reflectance of dried, ground extract as measured by a Cary Model 14 monochromator against a ceramic standard. These curves were then overlaid upon destriped AIS spectra ratioed to flat field spectra.

## RESULTS

### Vegetation and flat-field spectra

The flat field (freeway) spectra are shown in Figure 1. The shapes of the TREE and ROCK mode peaks between 1150 and 1350 nm are not very similar. This disparity probably results from effects of the blocking filter at 1100 nm used for ROCK mode data acquisition. The two spectra also differ beyond 1600 nm, where second order effects alter the TREE mode response (Vane 1986). These differences are obvious in TREE mode as a peak in the 1600-1800 nm region and a flattening of the two carbon dioxide absorption features in the 2000-2100 nm region (Weisner & Matson 1983).

Figure 2 compares flat-field corrected, destriped AIS spectra of Rhus laurina to similarly ratioed reflectance curves of the same species obtained with the field spectroradiometer (after deleting data in the atmospheric water absorption bands from the figure). The high noise in the field-derived spectra makes detailed comparison difficult, but some broad similarities in features appear to occur in the 900-1300 nm and 1500-1750 nm regions; second-order effects presumably explain the peak in TREE mode in a water absorption region near 1800 nm.

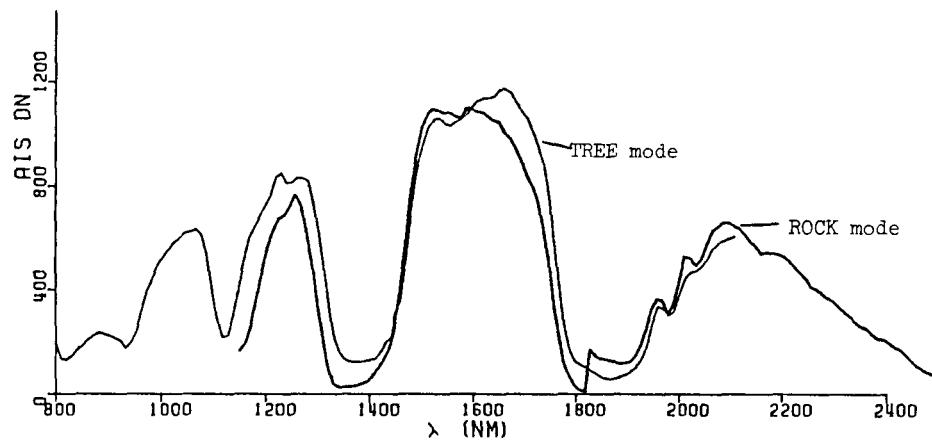


Fig. 1. Flat field spectra of AIS-2 data. A section of Interstate 5 at the east end of the Santa Monica Mountains was the area used.

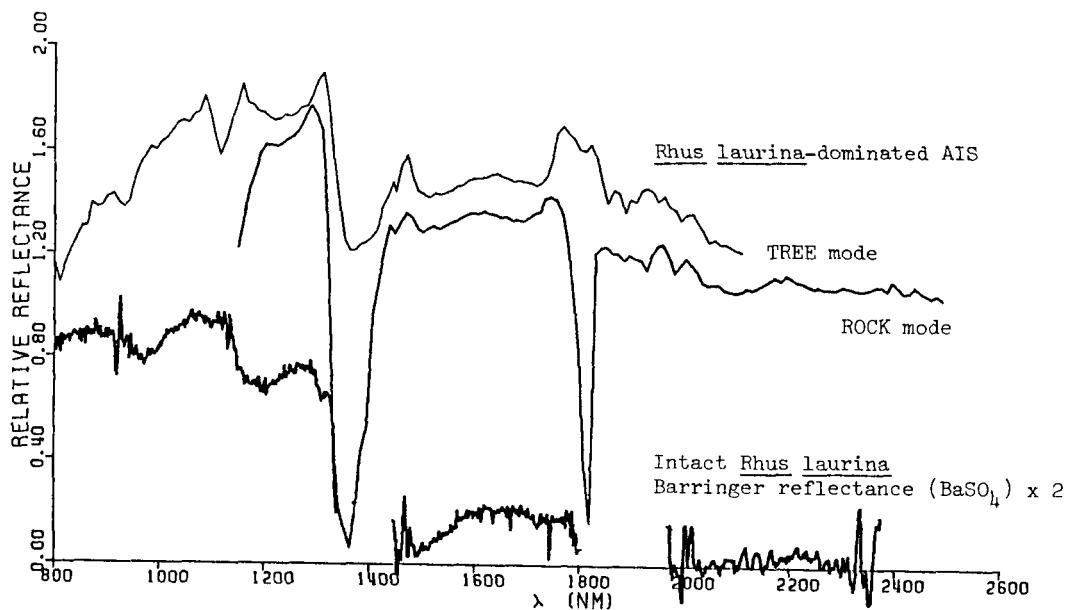


Fig. 2. AIS spectra over an area of dense Rhus laurina at La Jolla Canyon. The data were destriped and ratioed to a flat field. Lower curve is reflectance of Rhus laurina from the same location using a field spectroradiometer.

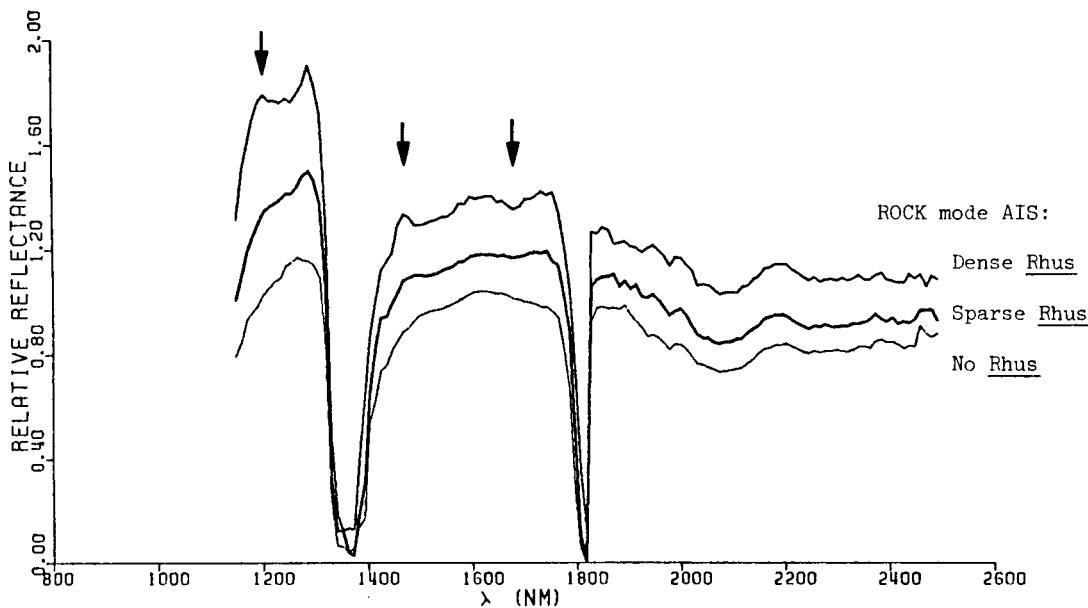


Fig. 3. AIS spectra for three areas dominated by Rhus laurina of different densities. AIS data are destriped, averaged over 3 X 3 pixels, and ratioed to a flat field. Note fine spectral variation between the three curves (arrows).

Figure 3 shows ROCK mode spectra extracted over coastal sage scrub of differing Rhus canopy closure. Each has been ratioed to flat-field spectra. The large differences in levels of reflectance between spectra are likely related to albedo (affected by sun and view angles), and possibly to leaf area index. Differences in fine spectral features (arrows) may arise from vegetation-induced spectral features independent of illumination angle. Further analysis is planned using log residual techniques to suppress the effects of varying scene illumination (Roberts et al. 1986).

#### Comparison to chemical spectra

Figure 4A compares the Rhus laurina-dominated spectra of Fig. 2 to reflectance curves for pure cellulose, starch and liquid water in filter paper. Liquid water has absorption peaks displaced 55-70 nm to longer wavelengths (1450 and 1940 nm, reported by Curcio and Petty 1951) compared to atmospheric water absorption maxima (1395, 1870 nm; Chahine 1983). These features can be seen in Figure 4A, and for plants in Figure 4B. The latter shows reflectance spectra from a canopy of intact seedlings of Pinus jeffreyi, measured with a Collins VIRIS spectroradiometer under artificial illumination (Westman and Price 1987).

The cellulose, starch, and water curves all show broad spectral features in Fig. 4A. The 1540 nm first overtone of an O-H stretching frequency, and a C-H first overtone at 1780 nm (bonds in starch and cellulose, and in the first case, water) occur in regions heavily influenced by water absorption. The AIS spectra cannot therefore be used with confidence to detect fine spectral features in these regions

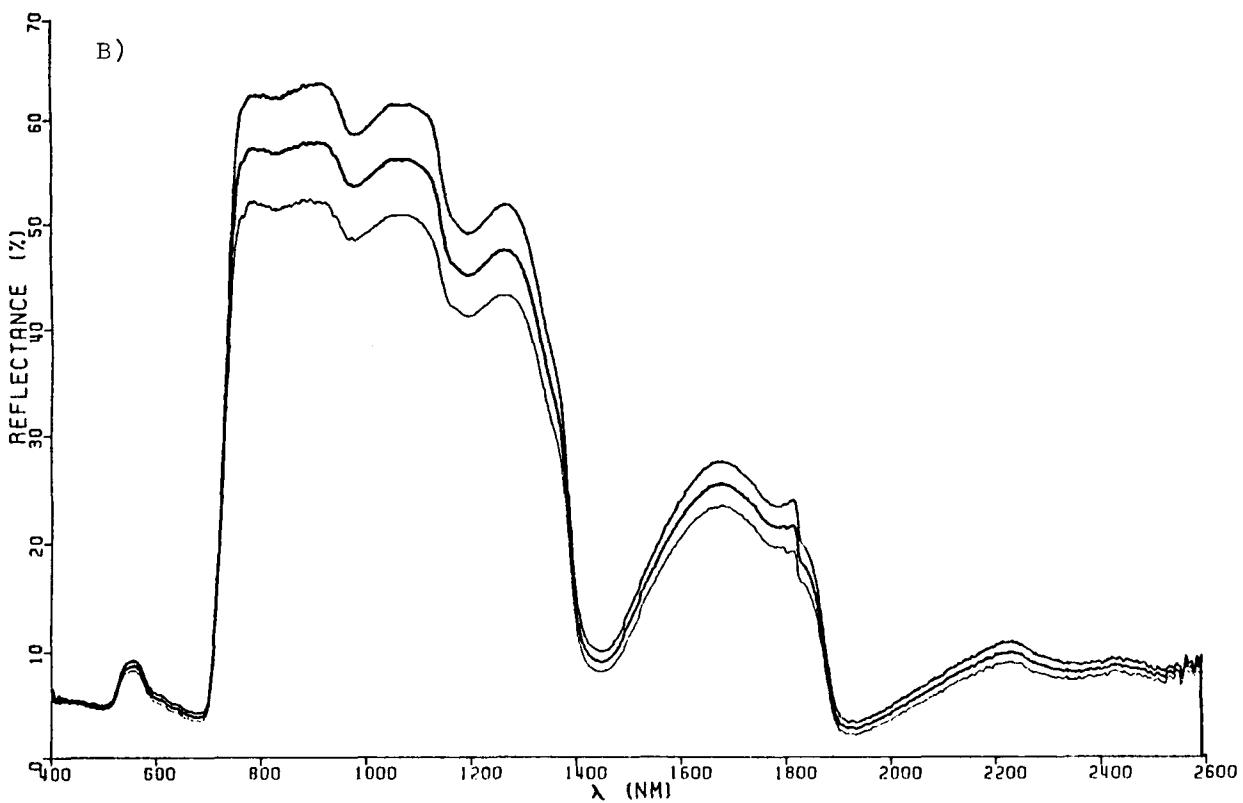
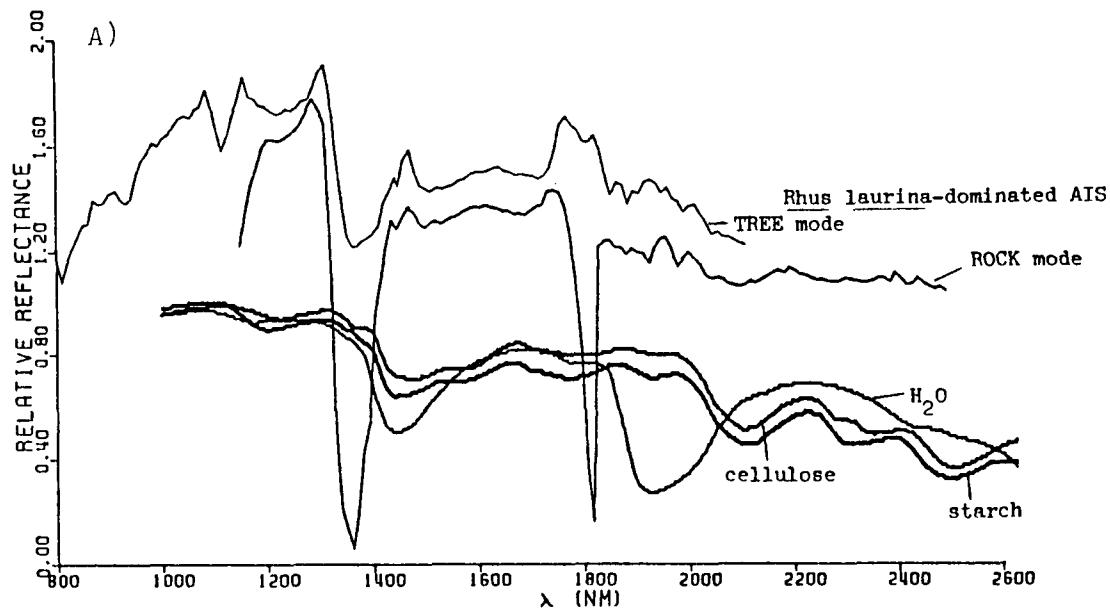


Fig. 4. A) Destriped AIS data of Rhus laurina-dominated areas, ratioed to flat field. Curves below are laboratory-derived reflectance curves for dried, ground extracts of starch and cellulose, and liquid water in soaked filter paper (adapted from Norris and Barnes 1976; Hruschka and Norris 1982). B) Reflectance of Pinus jeffreyi seedlings with Collins' VIRIS spectroradiometer. Upper and lower curves are standard errors.

because of the low signal/noise ratio resulting from absorption of much of the radiation by atmospheric water. The O=H bend/C-O stretch combinations at 2100 nm, and O-H stretch/C-C stretch combinations at 2270 nm (occurring in starch and cellulose) can be seen as absorption features in the pure cellulose and starch curves in a region where water absorption is less. These features at 2100 and 2270 nm in the cellulose and starch curves may or may not be responsible for the declines in reflectance in these regions in the AIS curve (ROCK mode). The green plant curve (Fig. 4B) shows a dip in the 2270 nm region, but not the 2100 nm region. The further dip in the starch and cellulose curves at 2500 nm is beyond the range of the AIS.

It does not appear possible, based on visual inspection, to determine whether the spectral features in the AIS curve are caused by absorption properties of the major plant chemical constituents, given present understanding. An understanding of the relative contributions of other features, including other chemical constituents, and other components of the scene, would be necessary for such a deterministic approach.

#### DISCUSSION

Each spectral region is influenced by many factors, but the combination of spectral features of any one chemical constituent are unique. In principal, therefore, reflectance at a combination of characteristic wavelengths could enable prediction of chemical concentrations. With the high level of intercorrelation that exists between chemical constituents in a leaf, and factors such as albedo or water content that affect large portions of a canopy reflectance spectrum, further intercorrelations between portions of the spectrum are introduced. For this reason, the potential range of wavelengths with high predictive power for a chemical constituent may be somewhat broader than implied by narrow stretching frequencies alone. Wessman et al. (1987) and Swanberg and Peterson (1987) report initial results in predicting leaf canopy chemistry from AIS spectra using stepwise regression to select wavelengths for prediction.

Research in the use of AIS spectra to predict canopy chemistry is in an exploratory stage. The spectra in Fig. 4 suggest that 2270 nm, and possibly 2100 nm, may be useful wavelengths to test in predictive models for the complex of glucose-based structural compounds such as starch, sugars and cellulose in plant canopies. Such deterministic approaches, as well as multivariate statistical approaches yet untried, remain for future testing.

#### ACKNOWLEDGEMENTS

Research was supported by NASA Earth Sciences Division under grant 677-21-35-08 and Life Sciences Division under grant 199-30-72-05. Research was conducted while one of us (W.E.W.) held a National Research Council research associateship at NASA Ames Research Center.

## REFERENCES

- Chahine, M.T. 1983. Interaction mechanisms within the atmosphere. In Manual of Remote Sensing, 2nd edn., ed. R. Colwell. (American Society of Photogrammetry, Falls Church, VA), pp. 165-201.
- Curcio, J.A. and Petty, C.C. 1951. The near infrared absorption spectrum of liquid water. *J. Optical Soc. Amer.* 41: 302-305.
- Hlavka, C. 1986. Destriping AIS data using Fourier filtering techniques. In Proc. 2nd AIS Data Analysis Workshop, ed. G. Vane and A.F.H. Goetz. (Pasadena, CA: NASA and Jet Propulsion Laboratory). JPL Publ. 86-35. Pp. 74-79.
- Hruschka, W.R. and Norris, K.H. 1982. Least-squares curve fitting of near infrared spectra predicts protein and moisture content of ground wheat. *Applied Spectroscopy* 36: 261-265.
- Jet Propulsion Laboratory. 1986. Supplement to the Science Investigator's Guide to AIS Data. (Pasadena, CA: Calif. Inst. Technology).
- Norris, K.H. and Barnes, R.F. 1976. Infrared reflectance analysis of nutritive value of feedstuffs. *Proc. 1st Int'l. Symp. Feed Composition, Animal Nutrient Requirements and Computerization of Diets*. Utah State Univ., Logan, Utah.
- Price, C.V. and Westman, W.E. 1987. Vegetation mapping and stress detection in the Santa Monica Mountains, California. *Proc. IGARSS '87 Symp.*, Ann Arbor, MI. Inst. Electrical and Electronic Engineers 87 CH2434-9. Pp. 1195-1200.
- Roberts, D.A., Yamaguchi, Y. and Lyon, R.J.P. 1986. Comparison of various techniques for calibration of AIS data. In Proc. 2nd AIS Data Analysis Workshop, ed. G. Vane and A.F.H. Goetz. (Pasadena, CA: NASA and Jet Propulsion Laboratory). JPL Publ. 86-35. Pp. 21-30.
- Spanner, M.A., Peterson, D.L., Acevedo, W. and Matson, P. 1985. High resolution spectrometry of leaf and canopy chemistry for biogeochemical cycling. In Proc. AIS Data Analysis Workshop, ed. G. Vane and A.F.H. Goetz. (Pasadena, CA: NASA and Jet Propulsion Laboratory). JPL Publ. 85-41. Pp. 92-99.
- Spanner, M.A. and Peterson, D.L. 1986. Analysis of AIS data of the Bonanza Creek Experimental forest, Alaska. In Proc. 2nd AIS Data Analysis Workshop, ed. G. Vane and A.F.H. Goetz. (Pasadena, CA: NASA and Jet Propulsion Laboratory). JPL Publ. 86-35. Pp. 144-152.
- Swanberg, N.A. and Peterson, D.L. 1987. Using the Airborne Imaging Spectrometer to determine nitrogen content in coniferous forest

canopies. Proc. IGARSS '87 Symp., Ann Arbor. MI. Inst. Electrical and Electronic Engineers 87 CH2434-9. P. 981.

Vane, G. 1986. Introduction. In Proc. 2nd AIS Data Analysis Workshop, ed. G. Vane and A.F.H. Goetz. (Pasadena, CA: NASA and Jet Propulsion Laboratory). JPL Publ. 86-35. Pp. 1-16.

Weisner, D.R. and Matson, M. 1983. Remote sensing of weather and climate. In Manual of Remote Sensing, 2nd edn., ed. R. Colwell. (American Society of Photogrammetry, Falls Church, VA), pp. 1305-1369.

Wessmann, C.A., Aber, J.D. and Peterson, D.L. 1987. Estimating key forest ecosystem parameters through remote sensing. Proc. IGARSS '87 Symp., Ann Arbor, MI. Inst. Electrical and Electronics Engineers 87 CH2434-9. Pp. 1189-1193.

Westman, W.E. 1987. Detecting early signs of regional air pollution injury to coastal sage scrub. In G.M. Woodwell, ed. Biotic Impoverishment: Changes in the Structure and Function of Natural Communities under Chronic Disturbance. Cambridge Univ. Press, Cambridge, England. In press.

Westman, W.E., Preston, K.P. and Weeks, L.B. 1985. Sulfur dioxide effects on the growth of native plants. In Sulfur Dioxide and Vegetation -- Physiology, Ecology, and Policy Issues, ed. W.E. Winner, H.A. Mooney & R.A. Goldstein. Stanford Univ. Press, Stanford, CA. Pp. 264-280.

Westman, W.E. and Price, C.V. 1987. Remote detection of air pollution stress to vegetation: laboratory-level studies. Proc. IGARSS '87 Symp., Ann Arbor. MI. Inst. Electrical and Electronic Engineers 87 CH2434-9. Pp. 451-456.